eRD102 – dRICH

Contact Persons: Evaristo Cisbani, Marco Contalbrigo, Anselm Vossen

Project Members: dRICH Group

DUKE, INFN-BA, INFN-BO, INFN-CT, INFN-FE, INFN-LNF,
INFN-LNS, INFN-RM1, INFN-TO, INFN-TS

August 31, 2021

The dual-radiator Ring Imaging Cherenkov (dRICH) detector is designed to provide continuous full hadron identification ($\pi/K/p$ separation better than 3σ apart) from ~ 3 GeV/c to ~ 60 GeV/c in the ion-side end cap of the EIC detector. It also offers a remarkable electron and positron identification from a few hundred MeV/c up to about 15 GeV/c. dRICH has been identified as reference detector for particle ID in the hadron endcap during the Yellow Report initiative.

The main technical goals for FY21 have been preparation of the basic version of the dRICH prototype, first test-beam, initial adaptation of the dRICH design to the EIC emerging detectors. The dRICH prototype is in advance construction phase, with the aim to be ready for a first test-beam scheduled at the H6 beam line of SPS, CERN in mid-September 2021. The test-beam will use mesons with momenta between 20 GeV/c and 60 GeV/c to cover the high-momentum spectrum of the EIC hadron end-cap and study mainly the gas imaging performance, possibly in conjunction with the aerogel, that works in saturated regime in this momentum interval. A second dRICH test-beam has been approved in October 2021 at the CERN T10 PS beam line to use mesons with momenta below 15 GeV/c to investigate the transient region between the two radiator regimes. The test is organized in synergy with ALICE and will have, as complementary targets, the study of the single-photon response of irradiated SiPM, and the comparative use of Russian and Japanese aerogel. The goal of these initial test-beams is to perform a commissioning of the dRICH prototype and to define what has to be improved to reach the design performance. During the test-beam, the functionality of all the ancillary systems (tracking, trigger and timing, cooling, gas and vacuum, readout) should be validated.

R&D plan for FY22 and FY23-24 preview: The main technical goals of FY22 are the completion of a test-beam setup able to demonstrate dRICH performance, a new test-beam to validate the dual-radiator approach and support the simulations, the study of dRICH basic integration into the EIC detector. FY23 and FY24 R&D will be targeted to optimization of the performance following EIC requirements, implementation of a EIC-driven photo-sensor and readout electronics and study of alternate cost-effective components and solutions to mitigate the construction risk.

Prototype: During FY22 and following years the prototype will be upgraded to reach the full functionality. The first version of the prototype and the 2021 test-beam campaign concentrate on the proof-of-principle of the dual radiator imaging and irradiated SiPM usage. The initial realization of the prototype, tracking and gas system will be not sufficient to fully characterize the performance of all the components and reach complete optimization. To reach these goals, the dRICH prototype needs to be complemented with improved systems before new test-beam campaigns. The foreseen improvements concentrate on the most delicate elements. Following the first test-beam outcomes, the detector boxes will be revisited to optimize cooling plates and sensor geometry; the mirror system will be complemented with remote controlled step-motors, to allow proper alignment while the prototype is in operation taking beam; a greenhouse gas recovery system will be realized to allow safe operations and relax restrictions due to environmental regulations. For most of the components, a commercially available suitable technology already exists as demonstrated by the developments pursued for the CLAS12 RICH: *e.g.*, customized aerogel of large area and high-clarity, use of composite materials for light mirrors of high optical quality, and stiff support structure of low density. However optimized performance and risk mitigation require (as explained below) the adaptation of the prototype to different components to seek for alternate qualified producers, cost reduction and improve performance. Examples are magnetic field tolerant photo-sensors and relative readout electronics, gas and aerogel radiators and their UV filtering septa, light mirrors. Financial support from INFN is expected to support part of these upgrades but a contribution from EIC project is essential for the prototype evolution and test-beam organization (50 k$ the first year, 20 k$ the following years).

Radiators: there are currently very few manufacturers of optical quality aerogel and even less with large production capability. Russian aerogel is basically an handcrafted product. Customization is possible towards world-leading performance in transparency and size, but the material is hydrophilic and requires special treatment. Mass production is possible but the production efficiency typically varies with time. Chiba University developed aerogel of excellent quality for the BELLE-II experiment and is now organizing a production facility called Aerogel Factory as spin-off. The quality and mass production capability need to be validated (the production for BELLE-II was done at the Japanese Fine Ceramic Company and reported issues for the largest refractive index). In USA, ASPEN company has pursued development programs for optical aerogel reaching decent transparencies at low refractive index. More recently, they collaborate with CUA to improve stiffness of very-low refractive-index aerogel. Funds are required (20 k$/yr) to acquire samples from this companies to assess the current status-of-the-art and initiate a customization program toward dRICH needs. Aerogel and gas refractive indexes need optimisation for photon yield, resolution and momentum coverage. Funds are requested (20 k$ in three years) to support the use of flurocarbon gases C_2F_6, and alternatives, in conjunction with properly associated aerogel. Given the LHCb experience that reported a long-term degradation of the aerogel when immersed in fluorocarbon gas, a septum between aerogel and gas radiator is recommended. Such a window could act as a wavelength filter to suppress the UV light component that mainly undergoes Rayleigh scattering in aerogel. A similar window may be needed to separate the gas volume from the active area (sensor and electronics). For the initial dRICH beam-tests a commercial 3 mm acrylic sheet will be used to study the prototype optical performance. In FY22 a study of the radiation tolerance of the septum material will be initiated. Funds are requested (20 k$ in three years) to acquire the relevant samples (acrylic and quartz).

Photosensor and Electronics: In order to meet the EIC specifications a critical element, common to other EIC PID detectors, is a proper choice of the photosensor, that should preserve single-photon detection capability inside a strong magnetic field. The dRICH focusing system is designed to keep the detector outside the EIC spectrometer acceptance, in a volume with reduced requests in terms of material budget and radiation levels. This feature makes dRICH a natural candidate for the exploitation of magnetic-field tolerant SiPMs. It is expected that the optimized solution will be developed by the end of FY23 within the Photosensor and Radiation-Hard SiPM generic programs in conjunction with the electronics/ASIC program. Nevertheless, any realistic study of the dRICH performance relies on the availability of a suitable instrumented area: at least $10 \times 10\,\mathrm{cm}^2$ with less than 3 mm pixelization and sub-nanosecond time resolution. To be compatible with SiPM and support streaming readout tests, such electronics should also cope with high rates, up to 0.5 MHz per channel. The reference sensors (Hamamatsu H13700) and readout electronics (MAROC3) derived from the generic R&D program, will be used in the initial dRICH test-beams but can not provide EIC wanted performance. In FY22, a realistic SiPM active plane and readout will be realized to meet the above basic specifications. The SiPM choice will be based on the initial survey and irradiation campaign performed in FY21. The readout will be based on the ALCOR chip, featuring an upgraded ToT architecture, and ARCADIA DAQ being developed at INFN, their initial adaptation to the dRICH needs being an INFN in-kind contribution. Funds are requested (40 k$ the first year, 20 k$/yr the following year) for acquiring status-of-the-art SiPMs and realizing the relative front-end boards with a baseline cooling integration.

Mirror: Being inside the EIC detector forward acceptance, the dRICH spherical mirrors should be light. Large area mirrors of optical quality compatible with RICH applications can be reliably produced at Composite Mirror Applications in Tucson, AZ, USA. CMA mirrors are made by two thin layers and a honeycomb core of carbon fiber reinforced polymer (CFRP) and achieve an areal density lower than 5 kg/m^2 and shaping accuracy better than 0.2 mrad. This company offers wide experience (HERMES, AMS, LHCb, CLAS12) and continuous improvements, but is unique. A R&D program connected with ATLAS is ongoing in Chile to realize composite mirrors at low cost that might reach adequate performance in the next years. The glass-skin technology (two thin glass sheets with an Al honeycomb core), developed in Italy for the terrestrial telescopes and used by CLAS12 RICH, can meet the required optical quality but, so far, only at large radii (more than 10 m). To meet dRICH requirements a shaping at high-temperature would need to be developed. In mirrors made of composite substrate, the surface roughness depends on the quality of the mold and stringent characteristics have to be imposed to obtain the needed roughness of 1-2 nm r.m.s. Good quality, homogeneous reflectance is critical in large surface mirrors and its characteristics and optimization requires the production and characterization of real-size mirror prototypes. Most likely, a process of iterations with feedback from the dRICH team to the producers will be necessary. To pursue these R&D dedicated funds would be required in FY23 and FY24 (30 k$/yr).

Engineering: The dRICH structure is divided in three main pieces. The aerogel volume, the gas volume and the photosensor boxes. The detector boxes, being outside acceptance, could be relatively massive to provide support for sensor, electronics and integrate services and cooling. Aerogel requires a support layer and an insulation window. While working at atmospheric pressure, the gas volume and mirror support could be realized by a skeleton of light CFRP ribs connected by tedlar foils (aka CLAS12 RICH). Fluorocarbon gases are ideal radiators because at atmospheric pressure and room temperature they exhibit high density, corresponding to high refractive index, and low chromatic dispersion in the visible range, resulting in high accuracy. However, fluorocarbon are greenhouse gases. Their market availability is subject to environmental regulations and a significant future price increase or shortage can not be excluded. When pressurized, noble gas density increases and they can mimic fluorocarbons very accurately: Argon at 2-2.5 bar absolute pressure can match EIC needs. Provided that the mirrors and the aerogel boxes are fixed to a rigid internal structure, some deformation of the entrance and exit window are compatible with dRICH operation and the material budget is essentially driven by safety regulations. An initial study will be pursued at INFN but would require a collaboration with BNL engineers to comply with the safety regulations. Funds are requested for technical support (30 k$ in three years).

Simulation and Integration: The dRICH concept can be adapted to different detector geometry and optimized in conjunction with other PID detectors. This can be primarily done with Monte Carlo simulations and CAD models, properly evolved following the prototype outcomes. Dedicated manpower is already working at DUKE and INFN but requires support to be able to continue the study.

Manpower: High-level expertise is available among the collaborating units covering all the aspects described above. INFN could count on 8 researchers (about 0.1 FTE each), several technicians and local infrastructures. DUKE on 2 researchers (about 0.05 FTE each). EIC funds would be crucial to co-fund young researcher positions and ensure dedicated manpower with long-term perspective. Three half post-doc positions are requested for a total of 100 k$/yr.

Milestones: Initial assessment based on the first test beams (3/30/22); Realization of a suitable detector plane for the dRICH prototype (6/30/22); Realistic implementation of dRICH into the EIC detector (9/30/22).

Funding profile: The dRICH project could count on a significant INFN in-kind contribution in infrastructures and expertise plus about 30 k$/yr covering the basic development, but relies on EIC project funds to mitigate the technological risk. Dedicated personnel can only be co-funded at this stage of the project. Continued financial support from the EIC project R&D program of the dRICH postdoc and their work on software as well as the dRICH prototype is crucial. The proposed funding profile and FY22 split is outlined in Table 1 and Table 2, respectively.

	prototype	radiators	mirror	detector	personnel	technical	travel	total
FY22	30	30	0	40	100	10	10	220
FY23	10	20	30	10	100	10	10	190
FY24	0	20	30	0	60	10	10	130

Table 1: Proposed EIC project funding profile in k$ (the assumed 30 k$/yr of INFN in-kind contribution is in addition).

	prototype	radiators	mirror	detector	personnel	technical	travel	total
INFN	30	30	0	40	60		5	165
DUKE					40		5	45
BNL						10		10

Table 2: Proposed FY22 project funding split in k$. It is assumed the prototype evolution is concentrated in EU due to COVID restrictions (the assumed 30 k$ INFN in-kind contribution is in addition).